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Training load monitoring and non-contact injury prevention in professional football

تسيير الحمل التدريبي والوقاية من الاصابات

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Abstract:

Quantifying training load and injury prevention in professional soccer poses complex challenges. It is crucial to develop accurate and reliable methods for measuring this load, taking into account physiological, biomechanical and psychological parameters. This quantification needs to be tailored to the specific needs of athletes, taking into account their fitness levels, goals and injury history.

Early identification of the risk factors associated with sports injuries is essential if effective prevention strategies are to be put in place. Integrating technological advances such as motion sensors and heart rate monitors into daily training management helps maximize performance while minimizing the risk of injury. Finally, promoting a responsible and safe training

Keywords: work load; Non-contact injuries; ACWR; Professional football

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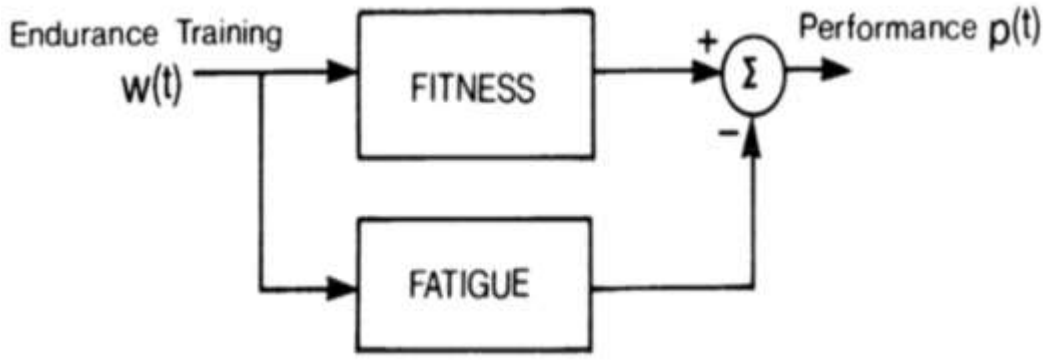
Introduction

In professional soccer, non-contact injuries are a major challenge, both for players and for medical and support teams. According to FIFA statistics for the year 2020, around 40% of all injuries occurring during professional soccer matches are non-contact injuries. Among the most common injuries are those affecting the hamstrings, adductors, cruciate knee ligaments and calf muscles. These injuries, often linked to sudden movements or changes of direction, can have a significant impact on players' careers and team performance.

On the other hand, training load monitoring is becoming increasingly popular in top-level sport to ensure that athletes obtain an adequate training stimulus and to minimize the negative consequences of training (risk of injury, overtraining). Various methods are used to monitor this load, both internally (RPE, TRIMP, HR, lactate concentration, etc.) and externally (speed, power, training volume, etc.). By simultaneously monitoring internal and external load, it is possible to measure the stress of training, both physiologically and psychologically, in order to individualize training programs and determine the optimum training load to improve performance.

Knowledge of this training load, both internal and external, makes it possible to model the achievement of performance by tracking the evolution of fatigue in relation to fitness, as proposed in the model by Bannister EW and Clavert TW (1980). (Figure 1)

Figure 1. Illustration of the training effect



Sours: Bannister EW and Clavert TW, 1980

In theory, every training session leads to an improvement in fitness, but it also generates fatigue. When chronic training load (CTL) is high, the athlete's fitness level increases. However, this is accompanied by an accumulation of fatigue over the sessions, which limits the expression of performance. Acute training load (ATL) enables accumulated fatigue to be monitored over a period, such as a week. To allow adaptations to be expressed, it is necessary to reduce the training load to reduce fatigue, and thus bring the athlete up to his or her best performance level. This approach is similar to that used in training for a major goal.

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Chronic training load (CTL) represents the amount of training the athlete has done in the past (e.g. average of the last 4-6 weeks of training). Chronic training load represents the overall load the athlete is used to supporting.

Acute training load (ATL) is the most recent training load for the current week.

1. Training load monitoring

Coaches and sports scientists increasingly recognize the value of systematic load-monitoring frameworks, which provide the tools needed to determine the optimal training dose capable of eliciting the most favorable physiological and performance adaptations. This principle, widely known as the "dose–response" relationship, is fundamental in high-performance sport. The central challenge lies in balancing stimulus and recovery: while substantial performance gains generally require the imposition of relatively high training loads, these same elevated loads can, if poorly managed, significantly increase the risk of overuse or acute injury.

A large body of research has investigated the association between training load and injury occurrence, often revealing a positive correlation between training intensity/volume and injury likelihood (Blanch & Gabbett, 2015; Colby et al., 2017). Simply put, the harder and more frequently athletes train, the more exposed they are to injury risk. On the other hand, reductions in training load have been shown to lower the probability of sustaining injuries (Wahl et al., 2013).

However, the widely held belief that high training loads are inherently detrimental is increasingly challenged. In reality, the athlete's individual profile—including training history, physiological capacity, recovery efficiency, and resilience—plays a decisive role in mediating the impact of high load. For some well-prepared athletes, sustaining a consistently high training load may actually confer a protective effect against injury (Hulin & Gabbett, 2018). This is particularly true when the chronic workload is stable and progressive, enabling the neuromuscular, metabolic, and connective tissue systems to adapt to sustained stress.

In this context, it is not the absolute magnitude of the training load that is most harmful, but rather the volatility in load exposure. Large, abrupt spikes—whether due to sudden increases in volume, intensity, or frequency—can overwhelm the body's adaptive mechanisms, leading to increased susceptibility to both acute and overuse injuries. For instance, epidemiological data suggest that approximately 40% of pre-season injuries are associated with sudden and pronounced increases in training load.

Therefore, weekly monitoring of training loads provides an important first layer of preventive analysis. This approach can identify both excessive spikes and prolonged underloading that may reduce conditioning levels. Yet, to move beyond descriptive statistics and gain deeper predictive insight, practitioners should integrate additional load indices—such as the Acute:Chronic Workload Ratio (ACWR), internal load markers (e.g., session-

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RPE, heart rate variability), and external load measures (e.g., GPS-tracked running metrics)—to better understand the dynamic interplay between workload, adaptation, and injury risk.

1.1 ACWR in training load management

The Acute-to-Chronic Workload Ratio (ACWR) reflects the balance between short-term training stress and longer-term training history. Conceptually, it is a streamlined adaptation of Banister's original Fitness–Fatigue model, in which moving load averages are used to compare an athlete's recent workload (acute; typically spanning the last 5–10 days) with their longer-term workload (chronic; generally over the past 4–6 weeks).

In team sports, a weekly training cycle is often the most practical measurement unit. The chronic load, calculated as the moving average over the preceding 3–6 weeks, is considered an indicator of an athlete's "fitness" level, whereas the acute load represents their current state of "fatigue" (Banister et al., 1975).

By expressing acute load as a ratio of chronic load, practitioners obtain an index of the athlete's readiness. When acute load is low—indicating minimal fatigue—and chronic load is high—reflecting well-developed fitness—the athlete is likely in an optimal state for performance, with an ACWR close to or below 1. Conversely, a high acute load combined with a low chronic load suggests that the athlete has undergone a sudden spike in workload without sufficient prior conditioning, placing them in a fatigued state. In such cases, the ACWR exceeds 1. This approach highlights both the beneficial and adverse effects of training, importantly relating current workloads to the training history for which the athlete is prepared (Hulin et al., 2014).

The first research to examine the link between ACWR and injury risk was conducted in elite cricket fast bowlers (Hulin et al., 2014). Training load was estimated using both session-RPE and the number of balls bowled. When the ACWR was ≤ 0.99—meaning acute load was equal to or less than chronic load—the 7-day injury risk was approximately 4%. However, when the ratio reached ≥ 1.5, corresponding to a weekly workload 50% greater than the athlete's prepared capacity, the likelihood of injury increased by a factor of 2–4.

Similar patterns have been observed in other sports. Using total weekly distance as the workload measure, elite rugby league (Hulin et al., 2016) and professional soccer (Ehrmann et al., 2016) players exhibited comparable injury risk profiles: when the ACWR exceeded 1.5, the probability of injury significantly increased.

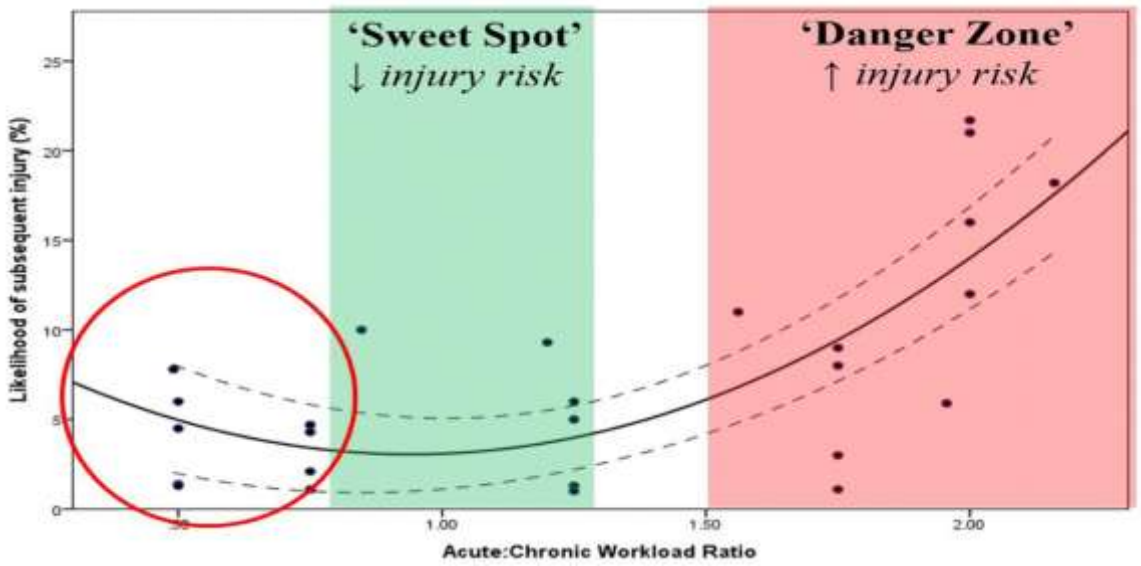
Drawing on evidence from cricket, Australian rules football, and rugby league, Blanch and Gabbett (2015) proposed interpretive guidelines for ACWR data (Figure 2). Ratios between 0.8 and 1.3 appear to represent the "sweet spot" for training, associated with relatively low injury risk, whereas ratios ≥ 1.5 are considered the "danger zone." To reduce injury likelihood, it is advisable to maintain the ACWR within the 0.8–1.3 range. However,

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since the load–injury relationship can vary by sport, these thresholds should be applied cautiously until further sport-specific evidence is available (Gabbett, 2016).

Figure 2. The acute/chronic load ratio



Sours: Blanch P and Gabbett Tim, 2015.

2. External workloads and injuries

In elite rugby league, research has shown that players covering greater distances of very high-speed running (VHSR) — specifically more than 9 meters per session at speeds exceeding 7 m/s — were 2.7 times more likely to sustain a non-contact soft tissue injury compared to those performing less VHSR per session (Gabbett & Ullah, 2012). This threshold of 9 m is notably lower than what is typically observed in other team sports such as soccer or Australian rules football (Varley, Gabbett & Aughey, 2014). The lower figure likely reflects the unique demands of rugby league, which involve greater physical contact, frequent repeated-effort actions, and lower continuous running requirements compared to these other sports.

Similarly, studies in Australian soccer have explored the relationship between total physical workload—measured using GPS and accelerometer technology—and injury risk. For instance, higher cumulative workloads over a 3-week period, such as a total distance of 73,721–86,662 m (odds ratio = 5.5) or a sprint distance exceeding 1,453 m (odds ratio = 3.7), were significantly associated with an increased likelihood of injury (Colby et al., 2014).

Further supporting this, Jaspers et al. (2017) reported that injury risk is influenced by a delicate balance between various external load measures (e.g., distance covered, sprint volume) and internal load markers (e.g., heart rate, perceived exertion). Both excessive increases and excessive decreases in these parameters can heighten injury risk, underscoring the importance of closely monitoring and adjusting load variables.

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Together, these findings highlight that load management in professional sports whether in rugby league or soccer—requires nuanced, sport-specific thresholds and the integration of multiple load indicators to optimize performance while minimizing injury risk.

Table 1 – Relationship between external workloads and risk of injury in elite rugby league players

Risk factors	Relative risk (95% CI)		
	Transient	Time lost	Missed matches
Injury history in the previous season (no vs yes)	1.4 (0.6 to 2.8)	0.7 (0.4 to 1.4)	0.9 (0.2 to 4.1)
Total distance (≤3910 vs >3910 m)	0.6 (0.3 to 1.4)	0.5 (0.2 to 1.1)	1.1 (0.2 to 6.0)
Very low intensity (≤542 vs >542 m)	0.6 (0.2 to 1.3)	0.4 (0.2 to 0.9)*	0.4 (0.1 to 2.8)
Low intensity (≤2342 vs >2342 m)	0.5 (0.2 to 1.1)	0.5 (0.2 to 0.9)*	1.2 (0.2 to 5.5)
Moderate intensity (≤782 vs >782 m)	0.4 (0.2 to 1.1)	0.5 (0.2 to 1.0)	0.5 (0.1 to 2.3)
High intensity (≤175 vs >175 m)	0.8 (0.2 to 3.1)	0.9 (0.3 to 3.4)	2.9 (0.1 to 16.5)
Very high intensity (≤9 vs >9 m)	2.7 (1.2 to 6.5)*	0.7 (0.3 to 1.6)	0.6 (0.1 to 3.1)
Total high intensity (≤190 vs >190 m)	0.5 (0.1 to 2.1)	1.8 (0.4 to 7.4)	0.7 (0.1 to 30.6)
Mild acceleration (≤186 vs >186 m)	0.2 (0.1 to 0.4)†	0.5 (0.2 to 1.1)	1.5 (0.3 to 8.6)
Moderate acceleration (≤217 vs >217 m)	0.3 (0.1 to 0.6)†	0.4 (0.2 to 0.9)*	1.4 (0.3 to 7.5)
Maximum acceleration (≤143 vs >143 m)	0.4 (0.2 to 0.8)*	0.5 (0.2 to 0.9)*	1.8 (0.4 to 8.8)
Repeated high-intensity effort bouts (≤3 vs >3 bouts)	0.9 (0.4 to 2.0)	1.6 (0.8 to 3.3)	1.0 (0.2 to 4.4)

Notes:

All injuries were classified as:
Transient = no training missed.
Time lost = any injury resulting in missed training.
Missed match = any injury resulting in a subsequent missed match.
*p < 0.05; p < 0.01.
Reproduced from Gabbett and Ullah.

Sours: Gabbett, Tim J and Ullah, Shahid . 2012.

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2.1 GPS and non-contact injury prevention

The application of Global Positioning System (GPS) technology for tracking training loads has become a standard practice in professional football. Initially, GPS was primarily used to describe player activity profiles during training sessions and friendly matches (Varley, M.C. et al., 2014). More recently, however, there has been increasing interest in leveraging GPS data to optimize the balance between training demands and recovery, with the goal of enhancing performance potential while minimizing the likelihood of overtraining (Kellmann, M., 2010; Meeusen, R. et al., 2013).

Within European competitions, professional players are absent for an average of 37 days over a 300-day season due to injuries (Ekstrand, J. et al., 2013a). This not only imposes a substantial financial cost on clubs but can also significantly jeopardize their competitive success (Hägglund, M. et al., 2021). The epidemiology of injuries in elite football is well-documented, with evidence showing that professional players face high injury risks both in training and, to an even greater extent, during matches (Hawkins, R.D. et al., 1999). The majority of these are soft-tissue injuries, with muscle strains in the thigh being the most prevalent (Ekstrand, J. et al., 2013b). Data also indicate that as many as 59% of reported injuries are non-contact in nature (Hawkins, R.D. et al., 1999).

Furthermore, recent findings suggest that injury incidence generally rises (2) — and match injury rates in particular increase (9) — when players have fewer than four days to recover between games. This indicates that residual fatigue plays a substantial role in injury risk. To mitigate fatigue-related injuries, it is essential to closely monitor players' training loads (Hooper, S.L., Mackinnon, L.T., 1995). Various approaches have been implemented to evaluate the impact of training on fatigue, such as heart rate monitoring (Hooper, S.L., Mackinnon, L.T., 1995), heart rate variability analysis, and hormonal profiling. Additionally, the session-RPE method has gained wide acceptance as a valid and reliable tool for assessing internal load (Scott, T.J. et al., 2013). Elevated training loads assessed via RPE have been linked to higher injury risk in elite youth football and other sports, including Australian Rules football and rugby league (Gabbett, T.J. et al., 2011).

In recent years, GPS tracking devices have been increasingly employed by football teams to quantify external training load objectively (Wehbe, G.M. et al., 2014). These systems have demonstrated adequate accuracy and reliability for workload assessment in team sports and have long been used in the Australian Football League and Rugby League. While most football studies using GPS have concentrated on movement patterns during matches and training, research has also examined the relationship between GPS-derived metrics and other load indicators. Key variables such as total distance covered, distances run at various intensities, and accumulated body load show significant correlations with subjective RPE-based training loads (Pedro, T.G.P. et al., 2011).

Nevertheless, the direct relationship between GPS-measured training loads and injury risk in football remains ambiguous. For example, Gabbett, T.J. and Ullah, S. (2012) reported associations between injury risk and high-intensity running volume during rugby league

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training, while Nielsen, R.O. and col. (2013) found that novice runners faced a greater likelihood of injury when their weekly mileage increased by more than 30% — although these findings were not statistically significant.

The work of Ehrmann, F.E. et al. (2016) identified two GPS-derived parameters with notable relevance for injury prevention in football: **average meters per minute** and **average new body load**. A substantial increase in meters per minute compared to the season average (by 9.6% over one week and 7.4% over four weeks), as well as a marked decrease in new body load (by 15.4% and 9.0% over one and four weeks, respectively), were both predictive of non-contact soft-tissue injuries in this cohort. These findings highlight both metrics as potentially modifiable risk factors. As such, meters per minute and new body load should be carefully monitored in retrospective training analyses and considered when designing future training programs.

3. Internal workloads and injuries

The UEFA Elite Club Injury Study (ECIS) seeks to tackle practical issues affecting elite football teams by offering recommendations grounded in scientific evidence. The process begins by consulting practitioners to understand their priorities and how sports science and medical research can support them.

Feedback from ECIS teams indicates that both match and training workloads—particularly those influencing internal load—are perceived as key risk factors. Consequently, they call for targeted scientific investigations that could yield practical guidelines (McCall A et al., 2016).

Historically, most research on injury and workload has centered on other football codes, such as rugby league and Australian Rules football (Stares J et al., 2017; Rogalski B et al., 2013). The 2016 consensus statement from the International Olympic Committee advises that high absolute workloads (e.g., acute weekly volumes, week-to-week fluctuations, multi-week accumulations) and elevated acute-to-chronic workload ratios—especially those exceeding 1.5—are associated with an increased injury risk. In contrast, higher chronic workloads maintained over several weeks (e.g., 2–4 weeks) may confer a protective effect (Soligard T et al., 2016).

While still limited, the body of research on workload–injury relationships in elite soccer is expanding (McCall A et al., 2016). Findings on internal load generally align with those from external load studies: higher training volumes are linked with increased injury incidence (Laura A et al., 2003).

Early investigations by Gabbett (2004a) in semi-professional rugby league revealed a strong correlation ($r = 0.86$) between training load—measured using session-RPE—and injury rates across a competitive season. A follow-up study over three seasons demonstrated that reducing training loads significantly lowered injury occurrence in the same group (Gabbett, 2004b). These observations suggest that high training loads, especially at the start of a season, may lead to overtraining and heightened injury risk (Gabbett, 2016).

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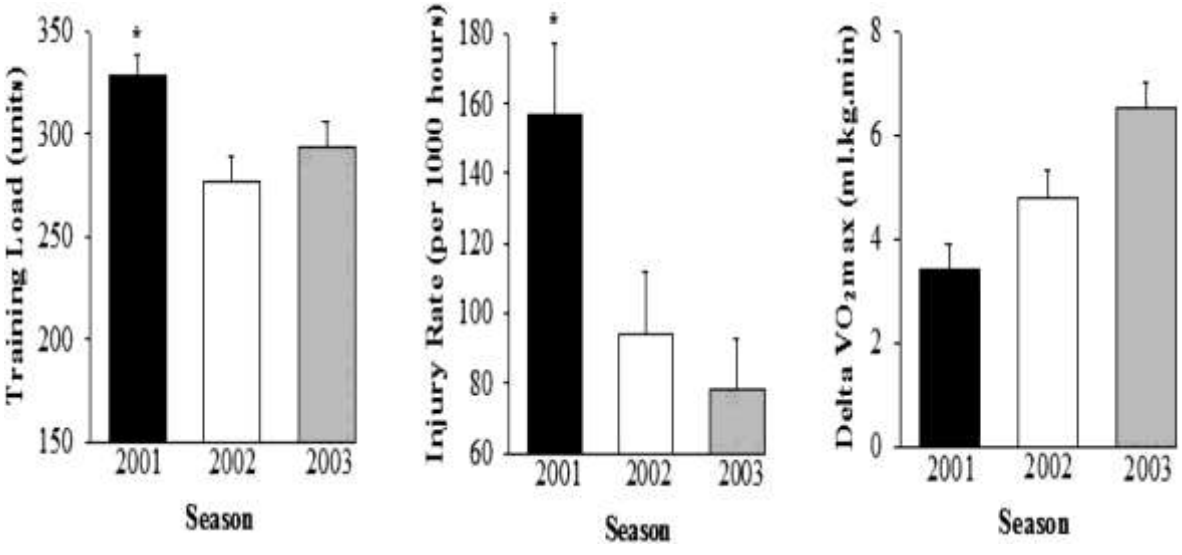
Additionally, McLaren SJ et al. (2017) reported that internal load indicators derived from perceived exertion and heart rate consistently show positive associations with external workload metrics such as running output and accelerometer data during both training and competition. However, the strength and reliability of these relationships vary depending on the measurement method and type of training performed.

Figure 3. Relationship between training load and injury rate in team sports athletes. Training loads were measured using the perceived exertion assessment method.



Sours: Gabbett Tim J 2004a ;Saoaud A & al.; 2016.

Figure 4. Influence of reduced pre-season training loads on injury rates and changes in aerobic fitness in team sport athletes. Training loads were measured using the perceived exertion assessment method.



Sours: Gabbett Tim J 2004b.

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In elite 15-a-side rugby league athletes, elevated cumulative loads over one week (exceeding 1245 arbitrary units) and over four weeks (surpassing 8651 arbitrary units) have been linked to a heightened risk of injury (Cross M. J. et al., 2016). Research on professional rugby league players has shown strong correlations between total training load and the occurrence of overall injuries (r = 0.82), non-contact field injuries (r = 0.82), and contact field injuries (r = 0.80) (Gabbett T. J. & Jenkins D. G., 2011). Notably, field training load demonstrated significant associations with overall field injury rates (r = 0.68), non-contact injuries (r = 0.65), and contact injuries (r = 0.63).

Strength and power training workloads also displayed significant relationships with injuries specific to those activities (r = 0.63). Interestingly, no significant link was found between field training load and strength/power injury rates. However, strength and power loads were strongly related to contact (r = 0.75) and non-contact (r = 0.87) field injuries.

Taken together, these findings indicate that (1) increased training intensity in rugby league is associated with greater injury incidence, and (2) heavy strength and power training may indirectly contribute to injuries sustained on the field. Consequently, systematic monitoring of workloads and strategic scheduling of field and gym sessions—designed to minimize residual fatigue—are crucial to reducing training-related injuries among professional rugby league players (Gabbett T. J., 2016).

4. Increasing training load from one week to the next: A critical element in injury occurrence

In 2016, Gabbett Tim J. and colleagues carried out multiple investigations to examine how weekly fluctuations in training load influence injury risk. Research by Piggott B. (2008) on Australian soccer players revealed that, although no statistically significant link was established between workload and illness, six illness cases occurred during the third week of pre-season. This period coincided with a 10% rise in training load compared to the previous week, with a moderate effect size (ES = 0.45). Foster (1998) similarly observed that sudden spikes exceeding 10% in training load metrics were followed, within seven days, by a considerable proportion of health issues—accounting for 42% of illnesses and 40% of injuries in the present study.

Rogalski B. et al. (2013) further demonstrated that players sustaining an in-season weekly load above 1750 AU faced a significantly greater injury risk than those below 1250 AU (OR = 2.44, 95% CI 1.28–4.66, p = 0.007). Likewise, a biweekly load surpassing 4000 AU was linked to a higher injury probability compared with a reference load under 2000 AU (OR = 4.74, 95% CI 1.14–19.76, p = 0.033). Cross M.J. et al. (2016) reported that absolute weekly load increases of roughly 1069 AU—equivalent to about 3.5 hours of average-intensity seasonal training—raised the likelihood of injury in the following week by around 60%.

The same year, Gabbett and colleagues modelled the relationship between week-to-week load changes, expressed as a percentage of the prior week, and injury probability.

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Their findings showed that when weekly changes were minimal (between 5% and <10%), injury risk remained below 10%. However, increases of 15% or more elevated injury likelihood to between 21% and 49%.

The first study examining the acute-to-chronic workload ratio (ACWR) in relation to injury risk was conducted among elite cricket fast bowlers. Results indicated that when acute load was equal to or less than chronic load (ACWR ≤ 0.99), the risk of injury within the subsequent seven days hovered around 4%. In contrast, an ACWR ≥ 1.5 increased the likelihood of injury two- to fourfold over the same period.

To mitigate injury risk, practitioners are advised to keep weekly workload increases under 10%. Maintaining stable training loads is key for injury prevention and for ensuring athletes can effectively adapt to demands. Nonetheless, strategic use of high-intensity training blocks (HITSM) with sufficient recovery can be beneficial for stimulating adaptation, provided that the athlete's autonomic nervous system (ANS) is carefully monitored. Ultimately, a well-planned and controlled workload strategy is vital to achieving a balance between injury prevention and performance enhancement.

5. What is the recommended approach to managing training load and preventing injury?

Drew M K & Finch C F. (2016) have compiled a list of evidence-based best practices to follow:

- Establish a moderate chronic training load
- Minimize week-to-week changes in training load
- Avoid exceeding an ACWR of 1.3
- Always maintain a minimum training load
- Avoid inconsistent load patterns
- Ensure that the training load is in line with the requirements of the discipline being prepared for
- Monitor the athlete's adaptive state after HITSM blocks to verify proper assimilation. HRV measurement could prove an effective tool in this case.

6. Conclusion

In conclusion, although there is a relationship between high training loads and injury, this article demonstrates that the problem lies not with the training itself, but rather with the inappropriate training that is prescribed. Excessive and rapid increases in training loads are probably responsible for a large proportion of non-contact soft-tissue injuries. However,

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physically hard (and appropriate) training develops physical qualities, which in turn protect against injury. This article highlights the importance of monitoring training load, including the load for which athletes are prepared (by calculating the acute/chronic workload ratio), as an exemplary approach to the long-term reduction of training-related injuries.

By following the evolution of ACWR, the coach can have a guide to optimize the training of the athletes he accompanies. ACWR represents an interesting approach to training programming, or to improving the fine-tuning phase before a major goal. ACWR monitoring is an important key to optimizing training and reducing the risk of training-related injuries.

ACWR is certainly an interesting and attractive method, but there is no single, miracle solution for monitoring training load! It's important to take other parameters into account.

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